GROUP ON EARTH OBSERVATIONS

CRITICAL EARTH OBSERVATION PRIORITIES

GEO TASK US-09-01a

Disasters Societal Benefit Area

Revised Report to the GEO User Interface Committee

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GROUP ON EARTH OBSERVATIONS

Group on Earth Observations

GEO Task US-09-01a:
Critical Earth Observation Priorities for Disasters SBA

Advisory Group Members & Analyst

The following people served as expert panelists for the *ad hoc* Advisory Group for the Disasters Societal Benefit Area (SBA) under GEO Task US-09-01a. The Advisory Group supported the Analyst by identifying source materials, reviewing analytic methodologies, assessing findings, and reviewing this report.

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The following person served as the Analyst for the Disasters Societal Benefit Area under GEO Task US-09-01a, providing overall coordination of the analysis and preparation of this report.

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Group on Earth Observations

GEO Task US-09-01a:
Critical Earth Observation Priorities for Disasters SBA

Summary

The goal of GEO Task US-09-01a is to identify the critical Earth observations for various societal benefit areas (SBAs). This analysis focused on identifying those requirements for the Disasters SBA, specifically for earthquake, landslide, and flood hazards. An *ad hoc* Advisory Group of 13 members from around the world was assembled to help narrow the focus of the analysis, to help identify documents from both developed and developing nations that identify Earth observation requirements for disasters hazards, and to review the methodology and results presented in the preliminary report. Participation from the Advisory Group varied among members and steps in the task.

Documents that potentially contained information related to the observation requirements were identified through literature and internet searches and through Advisory Group recommendations. After evaluating the documents for their applicability to this task, 22 were identified that provided information that could be used in the priority setting analysis.

Observation requirements were extracted from the documents for each of the three disasters hazard areas individually. To provide a more complete picture of what the documents were indicating as observation priorities, the observations were grouped or aggregated into broad categories. Using an indexing scheme that weighted observation categories by the frequency with which they were identified as observation priorities, as well as the type of document and cross-hazard applicability, a list of seven priority observation categories was generated. The following are the observation categories, in descending priority order:

- *Surface Deformation*
- *Topography/Elevation*
- *Seismicity*
- *Precipitation*
- *Soil Parameters*
- *Gravity Fields*
- *Magnetic Fields.*

These observation requirements represent a broad picture of global Earth observation requirements for disasters applications. The priorities of highest benefit to one geographic region may not provide any added value to another. However, regional, national and local-level authorities and agencies will be able to use such priority lists in helping develop Earth

observation strategies that are customized to their individual needs. This priority list, along with the specific physical requirements for the observations, will ultimately be incorporated into a broad cross-SBA analysis to be performed by GEO to identify critical Earth observations across all nine SBAs.

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1 Introduction

This report articulates Earth observation priorities for the Disasters Societal Benefit Area (SBA) based on an analysis of 22 publicly available documents, including documents produced by Group on Earth Observations' Member Countries and Participating Organizations.

1.1 GEO and Societal Benefit Areas

The Group on Earth Observations (GEO)[1] is an intergovernmental organization working to improve the availability, access, and use of Earth observations to benefit society. GEO is coordinating efforts to build a Global Earth Observation System of Systems (GEOSS)[2]. GEOSS builds on national, regional, and international observation systems to provide coordinated Earth observations from thousands of ground, airborne, and space-based instruments.

GEO is focused on enhancing the development and use of Earth observations in nine SBAs:

Agriculture	Biodiversity	Climate
Disasters	Ecosystems	Energy
Human Health	Water	Weather.

1.2 GEO Task US-09-01a

The objective of GEO Task US-09-01a is to establish and conduct a process to identify critical Earth observation priorities within each Societal Benefit Area and those common to the nine SBAs. Many countries and organizations have written reports, held workshops, sponsored projects, conducted surveys, and produced documents that specify Earth observation needs. In addition, researchers and practitioners have also identified and recommended key Earth observation needs in publications and peer-reviewed literature. Task US-09-01a focuses on compiling information on observation parameters from a representative sampling of these *existing* materials and analyzing across the materials to determine the priority observations.

This task considers all types of Earth observations, including *in situ*, airborne, and space-based observations. The task includes both direct measurements and derived parameters as well as

[1] GEO Website: *http:// www.earthobservations.org*
[2] GEO 10-Year Implementation Plan: *http://www.earthobservations.org/documents.shtml*

model products. This task seeks to identify Earth observation needs across a full spectrum of user types and communities in each SBA, including observation needs from all geographic regions with significant representation from developing countries.

GEO will use the Earth observation priorities resulting from this task to determine, prioritize, and communicate gaps in current and future Earth observations. GEO Member Countries and Participating Organizations can use the results in determining priority investment opportunities for Earth observations.

1.3 Purpose of Report

The primary purpose of this report is to articulate the critical Earth observation priorities for the Disasters SBA. The intent of the report is to describe the overall process and specific methodologies used to identify documents, analyze them, and determine a set of Earth observation parameters and characteristics. The report describes the prioritization methodologies used to determine the priority Earth observations for this SBA. The report also provides information on key challenges faced, feedback on the process, and recommendations for process improvements.

The primary audience for this report is the GEO User Interface Committee (UIC), which is managing Task US-09-01a for GEO. The GEO UIC will use the results of this report in combination with reports from the other eight SBAs. The GEO UIC will perform a meta-analysis across all nine SBA reports to identify critical Earth observation priorities common to many of the SBAs. Based on the nine SBA reports, the GEO UIC will produce an overall Task US-09-01a report, including the common observations and recommendations for GEO processes to determine Earth observation priorities in the future.

The report's authors anticipate that the GEO Secretariat, Committees, Member Countries, Participating Organizations, Observers, Communities of Practice, and the communities associated with the Disasters SBA are additional audiences for this report.

1.4 Scope of Report

This report addresses the Earth observation priorities for the Disasters SBA. In particular, this report addresses the sub-areas of earthquakes, landslides, and floods within the Disasters SBA (see Section 3 for more details).

The report provides some background and contextual information about the Disasters SBA. However, this report is not intended as a handbook or primer on the Disasters SBA and a complete description of the Disasters SBA is beyond the scope of this report. Please consult the GEO website cited above for more information about the Disasters SBA.

The report focuses on the Earth observations within the Disasters SBA, independent of any specific technology or collection method. Thus, the report addresses the "demand" side of observation needs and priorities. The report does not address the specific source of the

observations or the sensor technology involved with producing the observations. Similarly, any discussions of visualization tools, decision support tools, or system processing characteristics (e.g., data format, data outlet) associated with the direct use of the observations are beyond the scope of this report.

In this report, the term "Earth observation" refers to parameters and variables (e.g., physical, geophysical, chemical, biological) sensed or measured, derived parameters and products, and related parameters from model outputs. The term "Earth observation priorities" refers to the parameters deemed of higher significance than others for the given SBA, as determined through the methodologies described within. The report uses the terms "user needs" and "user requirements" interchangeably to refer to Earth observations that are articulated and desired by the groups and users in the cited documents. The term "requirements" is used generally in the report to reflect users' wants and needs; the use in this report does not imply technical, engineering specifications.

Following this introduction, the report discusses the overall approach and methodologies used in this analysis (Section 2). Section 3 describes the Disasters SBA and the specific sub-areas that were part of the analysis. Section 4 articulates the specific Earth observations for each Disasters sub-area, and Section 5 presents the priority observations across the Disasters SBA. Sections 6 and 7 present additional findings from the analysis of the documents and any recommendations. The Appendices include a list of acronyms used throughout the document and a list of the documents cited and consulted for this analysis.

2 Methodology

2.1 Task Process

The GEO UIC established a general process for each of the SBA Analysts to follow in order to ensure some consistency across the SBAs. This general process for each SBA involves nine (9) steps, as summarized in the following list:

Step 1: Identify Analyst and Advisory Group for the SBA
Step 2: Determine scope of topics within the SBA
Step 3: Identify documents regarding observation priorities for the SBA
Step 4: Develop analytic methods and priority-setting criteria
Step 5: Review and analyze documents for priority Earth observations needs
Step 6: Combine the information and develop a preliminary report
Step 7: Gather feedback on the preliminary report
Step 8: Perform any additional analysis
Step 9: Complete the report on Earth observations for the SBA.

A detailed description of the general US-09-01a process is available at the Task website *http://sbageotask.larc.nasa.gov* or the GEO website. Some steps in the process occurred

simultaneously or iteratively, such as identifying documents (Step 3) and reviewing documents (Step 5).

2.2 Analyst and Advisory Group

The Disasters SBA had an "Analyst" and an "Advisory Group" to conduct the process of identifying documents, analyzing them, and prioritizing the Earth observations. The Analyst served as the main coordinator to manage the activities.

2.2.1 Analyst

For the Disasters SBA, the Analyst was Stephanie Weber. Ms. Weber is a research scientist at Battelle. She received her Master's degree in Atmospheric Science and has over 5 years of experience in data analysis of atmospheric and land processes, including literature reviews and large-scale data gathering efforts.

For this task, the Disasters SBA Analyst served under contract to National Aeronautics and Space Administration (NASA) Applied Sciences Division.

2.2.2 Advisory Group

The outline for GEO Task US-09-01a includes the formation of an expert advisory panel to help identify appropriate documents, provide feedback on the analysis methods, and review the preliminary and final reports. For the Disasters SBA, the Analyst identified potential Advisory Group members through various sources. Members of the Integrated Global Observing Strategy (IGOS) Geohazards community of practice were solicited for their participation. In addition, the Analyst contacted participants from developing nations that participated in an international training course on the use of satellite data for Earth observation applications to evaluate their interests and areas of expertise. Other potential members were identified through organizational web sites, participation in major technical conferences, and publications.

Overall, between September and December 2008, the Analyst invited 36 scientists to participate by serving on the Advisory Group, or by recommending documents for the analysis. Thirteen scientists expressed an interest in serving on the advisory panel; five were unable to participate, but provided either document references or the names of alternate Advisory Group members; and 18 did not respond. For this task, it was important to have representation from both developed and developing nations so that a global view of disasters observation priorities could be captured. The 13 members of the Advisory Group included participants from nine countries across five continents. Table 1 provides a list of the confirmed Advisory Group members and their affiliations.

Table 1. Advisory Group for Disasters SBA.

Name	GEO Country or Organization	Affiliation	Geographic Region	Area of Expertise/ Specialty
Rosario Alfaro	Costa Rica	Instituto Meteorologico Nacional	South/Central America	
Jay Baker	United States	Florida State University	North America	Hurricanes/Floods
Jerome Bequignon	European Space Agency	European Space Agency	Europe	Disasters
George Choy	United States	United States Geological Survey (USGS)	North America	Seismic Hazards
Silvia Burgos Sosa	Paraguay	Paraguaian Institute for Environmental Protection	South/Central America	
Nicola Casagli	Italy	International Consortium on Landslides	Europe	Landslides
Mumba Dauti Kampengele	Zambia	National Institute for Scientific and Industrial Research	Africa	
Ivan Koulakov	Russia	Institute of Petrol Geology and Geophysics	Europe	Seismic Hazards
Goneri Le Cozannet	France	French Geological Survey	Europe	Disasters
William Leith	United States	USGS	North America	Seismic Hazards
Warner Marzocchi	Italy	World Organization of Volcano Observatories	Europe	Volcanoes
V. Madhava Rao	India	National Institute of Rural Development	Asia/Middle East	
Kaoru Takara	Japan	International Consortium on Landslides	East Asia	Floods/Landslides

All interested Advisory Group members were sent a description of the task, including a summary of what their role would be in the US-09-01a process. Also, each scientist was asked to supply document references that could be used in the analysis of priority observations. The Analyst held two conference calls and sent periodic emails to the Advisory Group throughout the course of the project to keep them apprised of the progress of the task, to request feedback on analysis methods and to inform them of existing gaps in document identification, including the lack of documents pertaining to smaller and/or developing nations.

2.3 Methodology

2.3.1 Documents

In order to identify as many publicly available documents as possible for consideration in the analysis of priority observations for the Disasters SBA, the Analyst and support team attempted to locate documents from various sources. The types of documents sought included international, regional, and national-level reports; workshop and conference proceedings, summaries and presentations; peer-reviewed journal articles; and other published documents. The Disasters SBA team used the following key methods in the document identification process:

- Requested document references for the three disasters subtopics directly from the Advisory Group.
- Searched the websites of large national and international working groups and government agencies. Examples of such working groups and agencies include the IGOS Geohazards Community of Practice, the US Subcommittee on Disaster Reduction (SDR), the Committee on Earth Observation Satellites (CEOS), USGS, and Bureau de Recherches Géologiques et Minières (BRGM- France).
- Performed web-based literature searches using standard search tools and databases. The Analyst used combinations of specific disasters and Earth observation keywords (e.g., earthquake, observation, priorities, spatial resolution, etc.) to perform the searches.
- Referred to the references listed in the documents identified through other methods to provide potential new sources of information.

2.3.2 Analytic Methods

Each document was evaluated for its usefulness based on the inclusion of specific observation requirements related to earthquakes, landslides, and/or floods. As a result, in order for a document to be included in the analysis, it had to explicitly identify required disasters-related Earth observations, and it had to contain information regarding the desired physical characteristics of the observation. The physical characteristics include the temporal resolution (frequency), spatial resolution, timeliness (how quickly the observation is available), accuracy/precision, and coverage or extent of the observation.

The Analyst performed a detailed data extraction process on the documents that met the criteria for inclusion in the analysis. All of the data extracted were compiled into a single database for further analysis. For each observation, the extracted information included the applicable disaster type(s) (earthquake/landslide/flood), the region of interest of the document (Global/Africa/Europe/Oceania/Asia and the Middle East/East Asia/North America/South and Central America), the type of document (e.g., international working group report, peer-reviewed journal article, conference proceedings, etc.) and the desired physical characteristics of the observation, where applicable.

In addition to extracting as much information from the reports into the database as possible, each observation parameter was grouped into a broader category of observations. The aggregation of certain parameters that are similar in nature in this way provides a more robust analysis, since individual observation requirements may not be frequently identified in the documents, but the effect could be larger if the observation were to be considered at the aggregated level. For example, precipitation duration, precipitation intensity, and precipitation amount were combined into a single "precipitation" category that was carried forward into the prioritization analysis.

For each of the disaster types, the Analyst constructed a table of the observation priorities, as well as the aggregated observation category, that were identified in at least one of the document references. References to the documents that explicitly identify each observation as a priority are also included in the tables.

2.3.3 Prioritization Methods

Using the data from the observation database generated during the document review process, a weighted index was computed in order to generate a list of priority disasters observations that is as objective as possible given the information and resources available. The index value for each of the observation categories takes into account how frequently the observation category is mentioned in the documents as a priority, as well as document -specific weighting factors based on the cross-cutting applicability of the observation category and a report weight based on the type of document.

The cross-cutting applicability weight for each document is an integer value from 1 to 3 that is equal to the number of disaster types (earthquakes, landslides and/or floods) to which a single observation applies, as identified by the document. This weight did not rely on the Analyst's judgment; rather it was assigned based only on the disaster types identified as applicable by the document.

The document weight is also an integer value from 1 to 3. International working group or consensus documents carry the highest weight with a value of 3, since they typically represent the viewpoints of scientists from a broad range of geographic locations and technical specialties. National-level government or working group documents have a weight of 2. The national-level documents are weighted slightly lower due to the narrowed geographic focus of the documents. Journal articles, conference presentations, conference proceedings, and unpublished studies have a weight of 1, as they typically represent the viewpoint of one or a few scientists, have a narrow geographic focus, and are not always subject to the peer-review process. Table 2 summarizes the weighting factors and gives examples of each document category.

Table 2. Weighting Factors for Index Computation.

Cross-Cutting Applicability		
Weight		**Definition**
1		1 Disaster Type
2		2 Disaster Types
3		3 Disaster Types
Document Type		
Weight	**Definition**	**Example**
1	Journal articles, conference presentations, conference proceedings and unpublished studies	Plag, H. P., 2006. "National Geodetic Infrastructure: Current Status and Future Requirements: The Example of Norway," Nevada Bureau of Mines and Geology, Bulletin 112, 98 pp.
2	National-level government or working group documents	National Academy of Sciences (NAS), 2007. "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond." ISBN: 978-0-309-10387-9; 456 pp.
3	International working group or consensus documents	Salichon, J et al., 2007. "IGOS Geohazards Theme Report", BRGM/RP-55739-FR, Bureau de Recherches Géologiques et Minières, August. 89 pp.

The document-specific index value for each observation category, i_{d_o}, is calculated by taking the product of the weighting factor for the number of disaster types applicable for the observation category in the document, w_{n_o}, and the weighting factor for the document type, w_d, as seen in Equation 1.

$$i_{d_o} = w_{n_o} w_d \qquad \text{(Equation 1)}$$

The final aggregated weighted index for each observation category, I_o, is calculated for all documents by taking the sum of the document-specific index values for the observation category over all of the documents (Equation 2).

$$I_o = \sum_d i_{d_o} \qquad \text{(Equation 2)}$$

By taking the sum of the index values over all of the documents, the aggregated index value takes into account how frequently the observation categories are identified as priorities. Those that are identified more frequently will have higher aggregated index values. The final aggregated index values are then used to rank the observation priorities across all three hazard types and all documents.

3 Disasters SBA

3.1 Disasters SBA Description

The Disasters SBA focuses on those natural- and human-induced events that can cause loss of life and property. Numerous events can be classified as disasters, such as weather related events, geologic phenomena, or human-induced incidents. The following is the brief statement of topics covered and key outcomes in the Disasters SBA from the GEOSS 10-Year Implementation Plan:

> *"Disaster losses can be reduced through observations relating to hazards such as: wildland fires; volcanic eruptions; earthquakes; tsunamis; subsidence; landslides; avalanches; ice; floods; extreme weather; and pollution events. GEOSS implementation will bring a more timely dissemination of information through better coordinated systems for monitoring, predicting, risk assessment, early warning, mitigating, and responding to hazards at local, national, regional, and global levels."*

Table 3 presents the disaster event types that are given particular attention in the GEO 2009-2011 Work Plan (GEO 2009b). Generic descriptions are included for informational purposes only.

Disasters affect millions of individuals around the world every year, causing human harm and substantial property damage. The Disasters SBA is focused on ensuring that the Earth observations necessary to help prevent (when possible), forecast, mitigate, respond to, and recover from disasters are available to the appropriate stakeholders across the globe.

Table 3. Disaster Types.

Disaster Type	Brief Description
Wildland fires	Uncontrolled natural or human-caused burning of forests or other large areas of land
Volcanic eruptions	Smoke, ash, and lava flow from volcanoes
Earthquakes	Shaking or vibration of the Earth's crust caused by the discharge of stress accumulated along geologic faults and other causes
Tsunamis	Extremely large waves or rapid change in sea level locally, often caused by an off-shore earthquake
Subsidence	Sinking or lowering of the ground
Landslides	The movement of a mass of rock, debris or Earth down a slope
Avalanches	The violent tumbling and sliding of snow down a mountain or other slope
Floods	Inundation of water over land, through heavy rain, overflowing rivers, or any other source
Extreme weather	e.g., violent storms, hurricanes, extreme heat and drought
Pollution events	Unhealthy levels of pollutants from a variety of potential natural and man-made sources.

3.2 Disasters Sub-Types

Step 2 of the Task US-09-01a process calls for the determination of the scope for the analysis. Due to the wide range of disaster types, as described in Section 3.1, the Analyst, in collaboration with the Advisory Group, narrowed the focus of the effort to a limited number of disasters subtopics. The Analyst began this process by sending an email survey to the Advisory Group, asking each member to identify the 2 to 4 subtopics that he or she felt should be included in this analysis. The Advisory Group was notified that future GEO efforts may include analysis of the other subtopics. A limited number of responses were collected from this survey. The Analyst held a follow-up conference call on 10 December 2008 to discuss the options and confirm the narrowed scope, with four Advisory Group members participating in the call.

The Analyst and Advisory Group concluded that *earthquakes, landslides, and floods* would be the focus of this iteration of Task US-09-01a for the Disasters SBA. The Advisory Group members noted that it is important to consider those disaster types that are the most severe in terms of frequency and impact, in addition to the availability of observations and the opportunities for mitigation using the data. The three disaster hazards chosen are well studied, and the Advisory Group indicated that the observation requirements sought for these hazards could help contribute to real needs for societal benefit. Other disaster types discussed by the Advisory Group members for inclusion were tropical cyclones, wildfires, and tsunamis. The Analyst relayed the outcome of the conference call to all members of the Advisory Group for feedback.

3.3 Documents

The document search effort, including website, database, and online literature searches and recommendations from Advisory Group members, yielded 52 documents that potentially contained Earth observation priorities for one or more of the disaster types. The Analyst performed a preliminary review of all of the documents to determine if the information provided specific disaster-related Earth observation requirements. If such observation requirements were included, the document was thoroughly reviewed and the Analyst extracted the appropriate data into a database.

Of the 52 documents initially identified, 22 (42%) of them contained Earth observation parameters that were extracted for further analysis. Although many of the documents are applicable for hazard observations anywhere on the Earth, half (11) of the documents were written by US organizations or scientists, with a North American focus. Seven documents specified observation requirements for Asia/Pacific regions, while one focused on Europe. The remainder of the documents were global in nature, with participating authors or contributors from all over the world. There were no documents focused on the requirements for Africa or South America, and this omission highlights a gap in identifying the priorities for the many developing nations on these continents.

4 Earth Observations for Disasters SBA

As stated in the summary of documents (Section 2.3.1), the goal of this task is to identify disaster observation priorities from documents that indicate the needs of both developed and developing nations. Although many of the observation priorities can be translated into global needs, the proportion of observations for each disaster type with a North American focus that was included in the analysis is very large compared to other geographic regions, as illustrated in Figure 1.

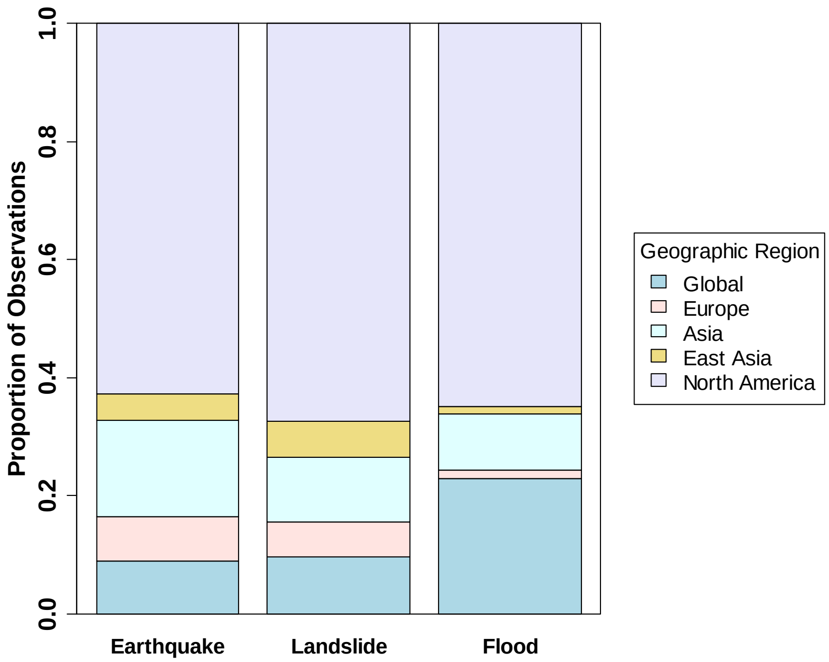

Figure 1. Proportion of observations by geographic region for earthquake, landslide and flood disasters.

GEO Task US-09-01a for the Disasters SBA seeks to identify specific Earth observation priorities from *in situ*, airborne, and satellite platforms, a number of secondary product requirements are mentioned in the documents that are not observations themselves, but that benefit from Earth observations. Examples include medium- and long-term forecast models that are forced by observations and hazard maps created through the aggregation of multiple Earth observations. Table 4 presents an example of a list of the secondary products mentioned in the documents; further analysis of these requirements is outside the scope of this task. This list contains requirements that were identified without specifying the types of observations needed to achieve the desired product.

Table 4. Example Secondary Product Priorities.

Hazard Maps
Risk Maps
Damage Assessment Maps
Infrastructure Status
Flood Plain Maps
Earthquake Frequency Maps
Improved Flood and Landslide Forecast Models

4.1 Earth Observations for Earthquakes

The sudden nature of earthquakes and other seismic hazards, and their ability to affect large areas, make them one of the most deadly and costly types of natural disasters (Salichon et al. 2007).

The physical mechanisms driving earthquakes do not lend themselves to the creation and adoption of accurate prediction methods. Earth observations related to earthquakes are useful for monitoring, assessing risk, locating fault lines and plate boundaries, developing mitigation strategies, and for post-disaster damage assessment.

The Earth observation priorities for earthquake hazards outlined in the documents are presented in Table 5. The parameters column indicates the specific observation, while the category indicates the broader description of the observations used for aggregation. The observations and specific parameters that are listed in the table are those that are explicitly identified in the documents as observation priorities for earthquake hazards.

4.2 Earth Observations for Landslides

Landslide disaster events are typically less severe than earthquakes, in terms of casualties, destruction, and economic consequences, but they are more widespread globally. Landslides occur when the shear stress on a slope exceeds the shear strength of the supporting material. The term “landslide” can be used to reference many types of down-slope Earth movements, including falls, flows (soil/rock, debris, lahar, mud), lateral spreads, slides (rotational and translational) and topple (USGS 2003). Landslides have a number of different triggering mechanisms and can be initiated by natural processes, such as earthquakes or other seismic events, volcanic events, and intense rainfall, or by anthropogenic processes including mining, vibrations caused by transportation routes, and increasing loads due to drastic changes in land use.

Table 5. Earthquake Observation Priorities.

Observation Category	Parameters	Document Reference(s)
General Weather	Length of Day	SESWG 2002
Global Positioning	Global Positioning	Plag 2006 NAS 2007 NRC 2003
	Terrestrial Reference Frame	
Gravity Fields	Gravity Fields	Helz and Gaynor 2007 Plag 2006 SESWG 2002 Salichon et al. 2007 NAS 2007
Ground Water	Ground Water	Helz and Gaynor 2007
Location of Faults	Location of Faults	Salichon et al. 2007 Bhanumurthy and Behera 2008 Tralli et al. 2005 HERP 1997
Magnetic Fields	Magnetic Fields	Helz and Gaynor 2007 SESWG 2002 Salichon et al. 2007 NAS 2007
Electric Fields	Electric Fields	Helz and Gaynor 2007
Seismicity	Seismicity	Helz and Gaynor 2007 USGS 2003 SESWG 2002 UNESCAP 2005 Turner et al. 2008 Salichon et al. 2007 Bhanumurthy and Behera 2008 USGEO 2006 NRC 2003 Tralli et al. 2005 HERP 1997
Soil Parameters	Soil Type	Bhanumurthy and Behera 2008
	Depth of Water Table	
Surface Deformation	Surface Deformation	Helz and Gaynor 2007 Plag 2006 SESWG 2002 ESNL 2004 UNESCAP 2005 Nirupama and Simonovic 2002 Salichon et al. 2007 Shimizu 2008 USGEO 2006 NAS 2007 NRC 2003 Tralli et al. 2005 HERP 1997
	Strain	
	Creep	
	Slip	
Thermal Emission	Thermal Emission	Salichon et al. 2007
Topography/ Elevation	Elevation	Helz and Gaynor 2007 SESWG 2002 ESNL 2004 Salichon et al. 2007 Bhanumurthy and Behera 2008 USGEO 2006 NRC 2003
	Bathymetry	

Earth observations of landslide parameters are used for the following applications (NOAA 2002):

- Mapping landslide-related factors
- Characterization of landslide deposits monitoring
- Prediction, monitoring, and mitigation
- Response
- Research.

Landslide hazard Earth observation priorities are presented in Table 6. The observations and specific parameters that are listed in the table are those that are explicitly identified in the documents as observation priorities for landslide hazards.

Table 6. Landslide Observation Priorities.

Observation Category	Parameters	Document Reference(s)
Flood Monitoring	Location of Flood	Shimizu 2008
General Weather	Temperature	Helz and Gaynor 2007 Salichon et al. 2007
Global Positioning	Global Positioning Terrestrial Reference Frame	Plag 2006 NAS 2007
Gravity Fields	Gravity Fields	Plag 2006 SESWG 2002 Salichon et al. 2007
Ground Water	Ground Water Level	Helz and Gaynor 2007 Spiker and Gori 2003
Land Use	Land Use	Tralli et al. 2005 UDRM 2006
Magnetic Fields	Magnetic Fields	SESWG 2002 Salichon et al. 2007
Precipitation	Precipitation Intensity Precipitation Amount Precipitation Duration	Helz and Gaynor 2007 Spiker and Gori 2003 SESWG 2002 Nirupama and Simonovic 2002 Salichon et al. 2007 Tralli et al. 2005 UDRM 2006 Catane et al. 2008
Seismicity	Seismicity	Helz and Gaynor 2007 USGS 2003 Spiker and Gori 2003 SESWG 2002 UNESCAP 2005 USGEO 2006 Catane et al. 2008

Table 6. (Continued).

Observation Category	Parameters	Document Reference(s)
Soil Parameters	Pore Pressure Soil Moisture Soil Composition Soil Thickness Soil Type Rock Strength Rock Spacing Rock Permeability Rock-Joint Orientation Rock Fracture	Helz and Gaynor 2007 Spiker and Gori 2003 SESWG 2002 Nirupama and Simonovic 2002 Salichon et al. 2007 Tralli et al. 2005 Catane et al. 2008
Stream/River Stage and Properties	Stream/River Height Stream/River Flow Stream/River Stage	Helz and Gaynor 2007 SESWG 2002 Tralli et al. 2005
Surface Deformation	Surface Deformation Strain Creep Slope Movement Slope Movement Rate Slope Movement Depth	Helz and Gaynor 2007 Spiker and Gori 2003 Plag 2006 SESWG 2002 ESNL 2004 UNESCAP 2005 Nirupama and Simonovic 2002 Salichon et al. 2007 Shimizu 2008 USGEO 2006 NAS 2007
Thermal Emission	Thermal Emission	NAS 2007
Topography/ Elevation	Elevation Slope Angle Slope Length Slope Position Curvature	Helz and Gaynor 2007 SESWG 2002 ESNL 2004 UNESCAP 2005 Salichon et al. 2007 Bhanumurthy and Behera 2008 USGEO 2006 NAS 2007 Tralli et al. 2005

4.3 Earth Observations for Floods

Floods are the most common natural disaster in the world, with frequent occurrence in most geographic regions, with the exception of the dry, desert regions. The nature of flood events makes it possible to use Earth observations for various stages of a flood disaster. Theses stages include the pre-flood stage, where flood forecasting, prevention, and preparedness are the key goals; during the flood event, where observations aid in weather and flood monitoring and response efforts; and for post-flood activities including damage assessment and forecast/model validation.

The Analyst applied the same methodology used to determine which observations were deemed as priorities in the reviewed documents for earthquakes and landslides to flood hazards. Table 7 presents the list of observation priorities and the aggregated observation category. The observations and specific parameters that are listed in the table are those that explicitly identified in the documents as observation priorities for flood hazards.

Table 7. Flood Observation Priorities.

Observation Category	Parameters	Document Reference(s)
Flood Monitoring	Location of Flood Flood Development Flood Peak	Brakenridge et al. 2003 NOAA 2002 Nirupama and Simonovic 2002 Shimizu 2008 Lauritson 2002 Bhanumurthy and Behera 2008
General Weather	Temperature Relative Humidity Wind Speed	Helz and Gaynor 2007 Nirupama and Simonovic 2002
Ice/Snow Parameters	Snow Cover Fraction Snow Liquid Water Equivalent Ice Location Ice Thickness Snow Pack Snow Albedo Snow Depth Snow Wetness	Helz and Gaynor 2007 NOAA 2002 Nirupama and Simonovic 2002 Lauritson 2002
Land Use	Vegetation Cover	Lauritson 2002 Tralli et al. 2005
Precipitation	Precipitation Intensity Precipitation Amount Precipitation Duration Precipitable Water	Helz and Gaynor 2007 SESWG 2002 NOAA 2002 UNESCAP 2005 Nirupama and Simonovic 2002 Lauritson 2002 Tralli et al. 2005 UDRM 2006
Soil Parameters	Soil Moisture Soil Wetness Index Pore Pressure Soil Composition Soil Thickness Soil Type Rock Strength Rock Permeability	Helz and Gaynor 2007 SESWG 2002 NOAA 2002 Nirupama and Simonovic 2002 Lauritson 2002 Tralli et al. 2005
Solar Influx	Solar Influx	Helz and Gaynor 2007

Table 7. (Continued).

Observation Category	Parameters	Document Reference(s)
Stream/River Stage and Properties	Stream/River Height	Helz and Gaynor 2007 Plag 2006 SESWG 2002 UNESCAP 2005 Tralli et al. 2005
	Stream/River Stage	
	Stream/River Flow	
	Stream/River Discharge	
	Stream/River Volume	
	Sea Level	
Surface Deformation	Surface Deformation	Shimizu 2008
Topography/ Elevation	Elevation	Helz and Gaynor 2007 SESWG 2002 NOAA 2002 UNESCAP 2005 Lauritson 2002 NAS 2007 Tralli et al. 2005
	Bathymetry	

5 Priority Earth Observations for Disasters SBA

This section contains the results from the prioritization method described in Section 2.3.3 applied to the observations identified in Section 4.

5.1 Summary of Results

The previous sections presented the observation priorities individually for earthquakes, landslides, and floods. After calculating the weighted index for each of the observation categories, the Analyst identified and ranked common observation priorities, shown in Figure 2. The index value can also be further broken down into the percentage that results for observations related to each disaster type. This information is also presented in Figure 2. The gray box highlights the top seven observation priorities. The method used to determine the top observation priorities is explained in Section 5.2.

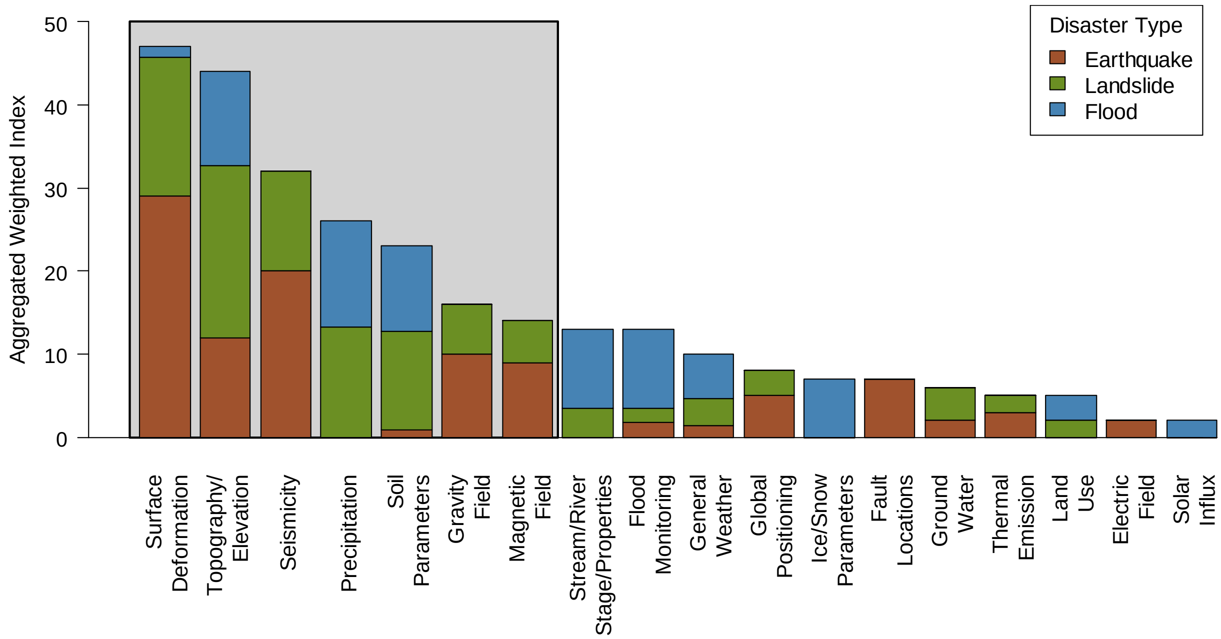

Figure 2. Aggregated weighted index value for all observation categories by disaster type.

5.2 Priority Observations

The remainder of this analysis will focus on those observations that are identified in this analysis as having the highest priority, defined as the top observation categories that cumulatively represent 75% of the total index value. These categories are highlighted in the gray box in Figure 2. Using this methodology, the Analyst identified seven categories as the top priority Earth observation categories for the Disasters SBA. The following is a more detailed discussion of the observation categories in priority order, including information regarding the desired physical characteristics of the observations provided by the documents. Table 8 provides a summary of the observation priorities and the desired characteristics for the seven priority observations.

Surface Deformation

Many of the documents reviewed refer to surface deformation observations using Interferometric Synthetic Aperture Radar (InSAR) and other remote sensing techniques as the highest priority for Earth observation missions related to natural disasters. As a result, surface deformation is the top priority Earth observation in this analysis. This result is likely due to the large number of documents used in this analysis that were focused on remote sensing applications of disasters Earth observations.

Surface deformation is a visible response on the Earth's crust to processes that are occurring at depth. These processes drive seismic activity, volcanism, and landslides

(NAS 2007). For disaster applications, various documents called for moderate to high spatial resolutions of surface deformation observations, ranging from a resolution of "less than 100 km" down to 1 m. Recently developed satellite surface deformation observation methods utilizing InSAR can provide global coverage with a higher resolution than is currently observed. Frequency specifications ranged from seconds to days to approximately weekly observations that coincide with the revisit time of polar-orbiting satellites with relatively narrow viewing swaths. These resolutions mainly applied to the displacement and strain accumulation observations. One document stated that the spatial and temporal resolution of the observations should be high enough to measure all significant motions, including seismic and aseismic events, as well as the transients that occur before, during, and after earthquakes. All documents that specified accuracy requirements indicated that sub-centimeter scale accuracy is required, with others going as far as to say that sub-millimeter is preferred. Several documents highlighted the need for these high-resolution, high-accuracy surface deformations in seismically active areas, along active fault lines and near fault zones.

Topography/Elevation

Measuring changes in topography was identified in many documents as critical for floods, landslides, and earthquakes. The spatial resolution required is described as "high" by many documents without further quantification, with one document mentioning that 1 m resolution is required in targeted areas and 2 to 5 m is required globally. The vertical accuracy identified in the documents ranges from sub-decimeter for targeted areas and 0.5 m elsewhere. Target areas include areas of high landslide susceptibility and seismically active areas.

Seismicity

Seismic monitoring, including surface and ocean-bottom seismometers, allows investigation of the magnitude of Earth shaking, as well as the timeframe and magnitude of aftershocks. The documents indicate that expansion of existing global, ground-based seismic monitoring networks is required. One document suggested that the network of ground-based monitors should be sufficiently dense (70 km on the national scale) to determine the source parameters, including the focal mechanisms of the seismic events. This document also recommended that additional monitoring be implemented in urban areas (1 to 2 km), as well in areas close to active faults. The sensitivity requirements vary among documents from a magnitude of 2.0 in seismically active areas to 3.0 to 3.5 elsewhere. These observations are required to be available in real-time to the end users.

Precipitation

The precipitation category includes observations of the intensity, duration, and amount of rain or snowfall that are used for flood prediction and monitoring, as well as for landslide applications. *In situ* rain gauges, Doppler radar, and geostationary satellites that provide meteorological data (e.g., Geostationary Operational Environmental Satellites, or GOES) meet the listed temporal resolution requirements of every 5 minutes to hourly. High temporal resolution is required since these variables can change rapidly. The documents identified a spatial resolution requirement that ranges from 1 to 50 km. Coverage

requirements indicated in the documents included near potential and actual landslides, in catchment areas, and in areas where flooding is taking place.

Soil Parameters
Soil properties in areas prone to floods and landslides are critical observations for prevention, prediction, and mitigation. These properties consist of the type of soil, the amount of water in the soil, the soil thickness, and rock properties, as well as the pore water pressure in the soil. The pore water pressure is an indicator of soil strength, a valuable parameter for landslide applications. The documents indicated a range of resolution requirements from 100 m to 10 km for soil moisture observations to 5 m for rock properties, with hourly to weekly revisit requirements, depending on the observation platform. One document indicated that a full soil composition and thickness assessment should be conducted every 5 to 10 years, while another specified that soil moisture observations should be available within one day.

Gravity Fields
Changes in the Earth's gravity field are another way to monitor near-surface deformation (SESWG 2002), and can provide information about the variation of stress with time when monitored after large seismic events (NAS 2007). Observations of the gravity fields along active faults and near fault zones were listed as priority observations in numerous documents. One document indicated an accuracy requirement for the gravity field as 0.3 μGal, while another stated that it should be within a few mm of surface water equivalent load. Although some documents called for global coverage of the Earth's gravity fields with approximately monthly frequency, others stated that these observations are particularly important along active fault lines and near fault zones.

Magnetic Fields
Similar to gravity fields, observations of the magnetic fields along active faults and near fault zones were listed as priority observations in numerous documents. One document indicated that the magnetic field from low-Earth gradiometers should be provided at an accuracy of within a few nT.

Table 8. Priority Earth Observations for Disasters SBA.

		Aggregated Characteristics of Priority Observation Parameters				
Observation Category	**Parameter**	**Coverage/ Extent**	**Spatial Resolution**	**Temporal Resolution**	**Accuracy**	**Latency**
Surface Deformation	Slip	• Seismically active areas • Along active fault lines/ near fault zones	• Moderate to High			
	Slope Movement	• Seismically active areas • Along active fault lines/ near fault zones	• 1 mm - 1 cm	• High Frequency		• Real-Time
	Strain	• Seismically active areas • Along active fault lines/ near fault zones	• 50 – 75 m	• Weekly	• Sub-cm	
	Deformation	• Seismically active areas • Along active fault lines/ near fault zones	• 1 m - 75 m	• 1 sec – 1 week • 1 month - 1 year	• sub-mm – 1 cm	
Topography/ Elevation	Elevation	• Global • Seismically Active Areas • Areas of high landslide susceptibility	• 0.15-5 m • 1 m for targeted areas • 2-5 m global	• Rapid updates after events • Monthly – 3 years	• sub-dm – 0.5m	• Months
	Bathymetry	• Near-Shore	• 90 m - < 1 km	• Monthly – 3 years		• Months
	Slope Angle, Length, Position	• Areas of high landslide susceptibility	• "High"			
	Curvature	• Areas of high landslide susceptibility	• "High"			
Seismicity	Seismicity	• National – Global Scales • Seismically Active Areas • Areas of high landslide susceptibility • Urban areas and critical facilities	• < 1 km - 2 km (urban areas) • 70 km (national scale)	• Real-Time	• Magnitudes of 1.5 - 2.0 (urban/regional) • Magnitudes of 3.0-3.5 (global)	• Real-Time
Precipitation	Precipitation Intensity, Duration, Amount	• Near potential and actual landslides • Catchment areas • Flood areas	• 1-50 km	• Continuous – Hourly • 2 times/day (satellite)	• 1 – 2 mm	• Hourly

a Blank fields indicate that no specific requirement was reported in the documents.

Table 8. (Continued).

		Aggregated Characteristics of Priority Observation Parameters				
Observation Category	**Parameter**	**Coverage/ Extent**	**Spatial Resolution**	**Temporal Resolution**	**Accuracy**	**Latency**
Soil Parameters	Soil Moisture		• 100 m - 10 km	• 4 times/day - weekly		• Within 1 day
	Soil Composition and Thickness			• 5 – 10 years • More frequent in affected areas		
	Pore Pressure					
	Rock Strength, Permeability, Spacing, Orientation		• 5 m			
Gravity Fields	Gravity Fields	• Global • Along active fault lines and near fault zones	• 100 km	• Approximately Monthly	• 0.3 µGal - 1 mGal	
Magnetic Fields	Magnetic Fields	• Global • Along active fault lines and near fault zones			• Few nT	

a Blank fields indicate that no specific requirement was reported in the documents.

6 Additional Findings

6.1 Comparison of Final Priority List with Other Priority Missions

Within the subset of documents that are analyzed in this study, there are two reports that clearly identify priority observation missions that are critical to the Disasters SBA. Although these documents analyze more disaster types than the three included in this analysis, they provide an overall picture of the priority observations across a variety of disaster types.

Table 9 presents the priority observation list, as defined in Section 5, as well as the priority observations identified in two other documents for comparison and validation purposes, "Living on a Restless Planet: Solid Earth Science Working Group Report" (SESWG 2002) and "Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond" (NAS 2007).

Table 9. Priority Observation Comparison.

Priority Observations from This Analysis	SESWG 2002	NAS 2007
Surface Deformation	X	X
Topography/Elevation	X	X
Seismicity		
Precipitation		
Soil Parameters		X *(Surface Composition)*
Gravity Fields	X	X
Magnetic Fields	X	X
Other	International Terrestrial Reference Frame	Thermal Properties

The priority-setting methodology employed in this analysis captures most of the observation priorities that were specifically identified as critical missions in the SESWG and NAS documents, except for seismicity and precipitation, which are not explicitly identified as priority observations in these documents. This omission is likely because the comparison documents are focused on remote-sensing technologies, and these two parameters are typically observed using *in situ* instruments. This fact is true for many of the other documents, as well.

> As this document was being finalized for submission to GEO, the Analyst was notified of a report by the CEOS Disaster SBA team (CEOS 2008) that establishes Earth Observation requirements for a variety of hazard types. The report gathered information from subject matter experts in satellite applications for disaster mitigation, warning, response and recovery. The Analyst reviewed the report and found that the priority observations identified in the CEOS (2008) document were very similar to those identified here through a literature review. While the CEOS document contained valuable information regarding observation requirements for earthquake, landslide and flood hazards, the Analyst did not believe that the final rankings presented in Section 5 of this report would have been altered by including the CEOS document in this US-09-01a analysis.

7 Analyst's Comments and Recommendations

7.1 Process and Methodology

Overall, the Analyst found that the steps outlined in the Task US-09-01a process were sufficient to accomplish the goal of identifying priority Earth observations for each SBA. As the entire process moves forward, and more SBA analyses are completed, the Analyst recommends that the UIC review the reports that have been completed to further refine the steps to ensure consistency and quality among all reports. Possible refinements include:

- Sending the invitation to participate in the Advisory Group directly from GEO, since some potential members may be hesitant to respond if they are not familiar with the Analyst's agency or organization. In addition, early contact by GEO may help to keep the Advisory Group engaged and active.

- Providing guidance on and specific examples of what should be considered an observation with respect to directly observed, derived, modeled and other types of parameters.

- Providing clarification on what language needs to be included in a source document in order for the identified observation to be considered a priority.

- Developing a standard for integrating the disparate sources of information into a single priority-setting analysis.

Appendix A: Abbreviations

BRGM	Bureau de Recherches Géologiques et Minières
CEOS	Committee on Earth Observation Satellites
GEO	Group on Earth Observations
GEOSS	Global Earth Observation System of Systems
GOES	Geostationary Operational Environmental Satellite
IGOS	Integrated Global Observing Strategy
InSAR	Interferometric Synthetic Aperture Radar
NASA	National Aeronautical and Space Administration
SBA	Societal Benefit Area
SDR	Subcommittee on Disaster Reduction
UIC	User Interface Committee
USGS	U.S. Geological Survey

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